

EFFECT OF COMPOSITION AND DENSITY ON THE  
ABLATIVE PERFORMANCE OF PHENOLIC-NYLON

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ABSTRACT

Results are presented from an experimental study of the effects of composition and density on the ablative performance of phenolic-nylon. Maximum effectiveness is obtained with densities of 25 to 30 lb/ft<sup>3</sup>, but thermochemical performance is not a strong function of either composition or density. Char spallation is observed under certain conditions, and this form of removal is most severe with high nylon content and/or low density.

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INTRODUCTION

Ablative materials are commonly used to protect spacecraft from the thermal environment encountered when entering planetary atmospheres. Char-forming ablators provide the most effective protection for a range of entry environments. Many charring materials have been formulated and tested; phenolic-nylon is representative of the best performing of these ablative materials (refs. 1 and 2). Under the test conditions of references 1 and 2 it was shown that a phenolic-nylon of 25 percent powdered phenolic resin, 50 percent powdered nylon, and 25 percent phenolic Microballoons, molded to a density of 36 lb/ft<sup>3</sup> had a high thermal protection effectiveness. This was a rather arbitrary formulation; other compositions and densities, based on the same materials, might provide superior ablative performance in particular applications.

Evaluation of the relative merit of a number of ablative materials for a given flight application is very difficult unless each of the candidate materials is sufficiently well characterized to permit calculation of its response to the entry environment. It is usually necessary to make a selection on the basis of the relative performance of the materials in a number of available ground test conditions. This procedure involves subjective judgment as to the significance of results, obtained at each test condition, in terms of the flight environment of particular interest.

This paper presents the results of an experimental determination of the ablative performance of phenolic-nylon of various compositions and densities. The materials were evaluated in three different thermal environments.

An important consideration in the selection of an ablative material for application to a flight vehicle is the ease of fabrication. The elevated temperatures and pressures required to mold phenolic-nylon could limit the

practicability of using this material as thermal protection for large space vehicles, or for vehicles with complicated shapes. It would be desirable to be able to mold the material at low pressures or perhaps even cast the material. The possibility of making a castable phenolic-nylon which is also an efficient thermal protection material was therefore included in this investigation.

#### TABLE OF SYMBOLS

$E$	ablative effectiveness, defined as $\frac{\dot{q}t}{w}$ , where $t$ is the time required for a back surface temperature rise of 300° F to occur
$\bar{E}$	ablative effectiveness based on the weight of material degraded, $\bar{E} = \frac{\dot{q}t}{\rho l_p}$
$f$	porosity of char
$\Delta h_{eff}$	effective heat of pyrolysis
$h_e$	stream enthalpy
$k_t$	thermal conductivity
$k_p$	permeability
$l_p$	thickness of material pyrolyzed
$M$	average molecular weight of gaseous products of pyrolysis
$\dot{m}$	rate of evolution of gaseous products of pyrolysis
$p$	pressure
$Q$	actual heating rate to surface/unit area
$\dot{q}$	cold wall convective heating rate to nonablating surface/unit area
$R$	gas constant
$\dot{s}$	char surface recession rate at stagnation point
$T$	absolute temperature
$t$	time
$w$	original weight of ablation material/unit area

y	coordinate normal to surface
$\beta = \frac{k_t}{\sigma \epsilon} [T_S^2 + T_P^2] (T_S + T_P)$	
$\delta$	char thickness
$\epsilon$	surface emissivity
$\mu$	viscosity of gaseous products of pyrolysis
$\rho$	density of original material
$\rho_g$	density of gaseous products of pyrolysis
$\sigma$	stress
$\sigma_{SB}$	Stefan-Boltzmann constant

#### Subscripts:

o	reference value
p	pyrolysis
s	char surface

### MATERIALS

The ablation material used in this study is in general referred to as low-density phenolic-nylon. This material is composed of a nylon powder, a phenolic bonding material, and phenolic Microballoons. The nylon used is DuPont Zytel 103 purchased from the Liquid Nitrogen Processing Corporation. According to the manufacturer's specifications, the average particle size of the nylon powder was 80 mesh with a maximum size of 30 mesh. The phenolic bonding material was Union Carbide BRP-5549, a pulverized, heat reactive phenolic resin with average particle size of 200 mesh. The phenolic Microballoons, which are a cured phenolic resin in the form of minute hollow spheres, were Union Carbide BJO-0930. The Microballoons were 270 mesh average with a range from 50 mesh to sizes which would not pass through a 400 mesh screen.

In this investigation, the ablative composites were molded from the above materials using various percentages of these three components. A total of eight different compositions were investigated. Each composition in the original program was molded to a nominal block density of 36 lb/ft<sup>3</sup>. In addition, three of the compositions were molded to various block densities ranging from about 18 lb/ft<sup>3</sup> to 43 lb/ft<sup>3</sup>.

After a few tests were conducted, it seemed desirable to try a composition of 35 percent phenolic, 30 percent nylon, and 35 percent Microballoons, with densities of 24 and 30 lb/ft<sup>3</sup>. The compositions and the corresponding densities considered are shown in Table 1. The densities given in the table are nominal values for 11-inch-diameter by 2-inch-thick blocks of ablation material. The densities of the individual test specimens varied slightly from these block values.

The materials were mixed at room temperature in a V-type blender with a capacity of 1 cubic foot. The blender tumbled the materials at a rate of 22 rpm. The mixed materials were molded in an 11-inch-diameter mold, in vacuum, at a temperature of 320° F for a period of 2 hours. The materials were then cooled in the mold to room temperature. The materials were molded to a given volume to obtain the required density for each block of ablation material. The initial molding pressure varied from about 100 psi to 250 psi. The individual test specimens were machined from the 11-inch-diameter blocks and attached to a holder for positioning on the test apparatus.

To study the feasibility of using a casting process in fabricating phenolic-nylon heat shields, a liquid phenolic resin system was used for some specimens, instead of the customary powdered phenolic resin. The liquid resin was EC 251 produced by Evercoat Chemicals Inc. The Mylar and Microballoons were the same as those used in the powdered system. The materials were mixed for 1/2 hour at room temperature in a vertical cone mixer and then cast at atmospheric pressure at a temperature of 200° F for a period of about 18 hours. As with the powdered resin systems, specimens were made with various percentages of the raw materials. However, only one density of each composition was considered and each composition had a different density. The compositions and corresponding densities of specimens cast from liquid resin are given in Table 1. A number of specimens were molded from the liquid resin system, as indicated in Table 1, so that effects of processing could be separated from the effects of using a different phenolic resin.

#### TEST FACILITIES AND TEST CONDITIONS

The various material compositions were tested in three arc heated jets. These facilities and the test conditions which were used are described below. The test conditions are summarized in Table 2.

The first series of tests was conducted in a 2500-KW subsonic atmospheric-pressure free jet which is described more fully in Reference 3. The tests conducted in this facility were similar to those reported in Reference 1. However, the specimens were 1 inch thick rather than of such thickness that the weight was 3 lb/ft<sup>2</sup>. Also, the stream contained 3 percent oxygen rather than 23.2 percent. These test conditions are summarized in Table 2. Each specimen was subjected to the constant thermal environment at its front surface until a rise of 300° F occurred at a calorimeter bonded to the back surface. The ablative effectiveness of the material was determined from the following equation:

$$\bar{E} = \frac{\dot{q}t}{w} \quad (1)$$

This effectiveness is the amount of heat accommodated at the surface per unit weight of material originally available. The time  $t$  is the time at which a back surface temperature rise of 3000° F occurs, and  $\dot{q}$  is the cold wall convective heating rate obtained from a calorimeter test calibration of the jet. The specimen weight per unit of area is  $w$ .

A second series of tests was conducted in the 6-inch Subsonic High-Temperature Arc Tunnel which is described in reference 4. This facility has been modified to operate at supersonic velocities, and was operated in a choked condition to obtain fairly high stagnation pressure and heating rate. These tests usually lasted 10 seconds, although in some instances the specimen was completely consumed in a shorter time. A few tests of the better materials were extended to longer times. Data obtained from these tests consisted of motion pictures of the test and measurements of total surface recession and final char thickness. No specimen temperature measurements were made in these tests.

The third series of tests was conducted at the highest enthalpy level of the three test series. The tests were conducted in a subsonic free jet exiting to the atmosphere. The jet was heated by a Thermal Dynamics Corporation 1-megawatt F5000 Arc System. The stagnation pressure was approximately 1 atmosphere. This facility has not yet been equipped to prevent some convective heating to the back side of the specimens. Therefore ablative performance was determined from post-test measurements of surface recession and char thickness, rather than from back surface temperature measurements. The results were evaluated on the basis of a modified effectiveness parameter defined as follows:

$$\bar{E} = \frac{\dot{q}t}{\rho l_p} \quad (2)$$

where  $\bar{E}$  is the amount of heat accommodated per unit weight of material degraded,  $t$  is the test duration,  $\rho$  is the density of the original material, and  $l_p$  is the thickness of material pyrolyzed.

## RESULTS AND DISCUSSION

The experimental results are summarized in Table 1, and the nominal test conditions are presented in Table 2. These results are discussed in detail in the following sections.

### Experimental Results

Test Condition I.—Results of the tests conducted under Condition I (Table 2), on molded specimens, are shown in Figure 1. For the range of compositions and densities investigated, effectiveness ranges from about 10,000 to

16,000 Btu/lb. Maximum effectiveness is obtained for densities between 24 and 30 lb/ft<sup>3</sup>. The effect of composition on effectiveness, over the range covered, is less than 10 percent from the midpoint of the data, at a nominal density of 36 lb/ft<sup>3</sup>.

In general, decrease in effectiveness with increasing density would be expected because of the lower insulating value (on a weight basis) of the higher density material. In addition, the conductivity of the uncharred material at about 2000° F (Fig. 2) appears to increase linearly with density. The rapid increase in the  $k_t\rho$  product of the material accounts for the decrease in effectiveness as density increases beyond 30 lb/ft<sup>3</sup>.

The increase in effectiveness with increasing density at densities below 24 lb/ft<sup>3</sup> results from the improvements in the physical characteristics of the char. From Figure 3 it is seen that, for a given composition, char uniformity increases with increasing density over the entire density range investigated. With the higher densities, the materials in Figure 3b were completely charred and flow of the test stream through the outer edge of the char resulted in the irregularities which are observed at the edges. Attention should be restricted to the stagnation area of the specimens. While no mechanical removal (spallation) of char was observed in these tests, the extreme surface roughness of the chars produced from the lowest density material of either composition could result in increased heating, or penetration of the test streams into the char. Thus, density has two effects on performance. First, insulating effectiveness decreases with increasing density, and this is the controlling effect at densities above 30 lb/ft<sup>3</sup>. Second, char uniformity improves with increasing density. This latter effect is predominant at densities below 25 lb/ft<sup>3</sup>, at least for this environment.

From a comparison of the two lowest density materials shown in Figure 3, it is seen that the material having 40 percent nylon provides the more uniform char. At higher density, the material containing 50 percent nylon provides the more uniform char. Detailed examination of the data (Fig. 1) shows that in general higher effectiveness is associated with the more uniform char. The effectiveness data for the material compositions shown in Figure 3 is plotted in Figure 4.

High-Pressure Tests.— These tests (test condition II, Table 2) were conducted primarily to evaluate the mechanical integrity of the char layers formed by materials of varying composition and density. The results fell in three categories. In some cases, no mechanical removal of char was observed. In others, a char of appreciable thickness was built up and then periodically removed, with a period of several seconds. Finally, with some materials the spallation was almost continuous. A brightening of small portions of the surface, indicating accumulation of char, was followed by darkening, indicating char removal. These events occurred sporadically, rather than simultaneously, over the entire surface.

The effect of density on char surface recession rate is shown in Figure 5 for several compositions. The average rate of recession, even when weighted by the initial density as in the figure, decreases rapidly with increasing density.

The recession resulted almost entirely from mechanical spallation. The large amount of scatter in the data results because in some cases spallation occurred just prior to termination of the test while in other cases it would probably have occurred shortly if the test had not been terminated. However, the material containing only 40 percent nylon is definitely superior to the other compositions at each density. The effect of nylon content on surface recession is shown in Figure 6. In this test condition, in each case higher nylon content results in higher surface recession rates.

The periodic spallation which was observed in these tests consisted of complete local removal of the char at the interface between char and uncharred material. This type of char removal might result from tensile failure at the interface caused by the internal pressure built up by gaseous products of pyrolysis. An approximate equation for the stress at the interface as a result of internal pressure is derived in Appendix A. This stress is

$$\sigma = \frac{1}{1-f} \left\{ f \left[ \left( \frac{\mu_o R}{2\sigma_{SB} M_o T_p^2} \right) \left( \frac{\delta}{\delta + \beta} \right) \left( \frac{Q k_t}{\Delta h_{eff} \epsilon k_p} \right) + p_s^2 \right]^{1/2} - p_s \right\} \quad (3)$$

When typical values are substituted for some of the parameters in equation (3), the following result is obtained:

$$\sigma = \frac{1}{1-f} \left\{ f \left[ 10^{-9} \frac{ft^4-sec}{Btu} \left( \frac{lb}{in.^2} \right)^2 \left( \frac{\delta}{\delta + 0.02 ft} \right) \frac{Q}{k_p} + p_s^2 \right]^{1/2} - p_s \right\} \quad (4)$$

The permeability of chars has not been measured. If it is assumed that  $\sigma_{ult} = 50$  psi,  $f = 0.8$ ,  $p_s = 27$  psi, and  $Q = 200$  Btu/ft<sup>2</sup>-sec, then the relation between permeability and char thickness at failure is approximately

$$10^{11} k_p = \left( \frac{\delta}{\delta + 0.02 ft} \right) ft^2 \quad (5)$$

If the permeability is greater than  $10^{-11}$  ft<sup>2</sup>, this form of char removal would not be obtained. In reference 5 the permeability of a char formed from pyrolyzed phenolic resin was estimated to be  $1.72 \times 10^{-15}$  ft<sup>2</sup>. Therefore failure as a result of internal pressure does offer a possible explanation for the observed performance.

The parameters in equation (3) which are most likely to vary with material density and composition are permeability and porosity. Decreasing density and increasing nylon content would be expected to result in higher porosity and perhaps higher permeability. Higher porosity would increase the stress level, while higher permeability would reduce it. Thus the effect of composition and density on porosity is probably in the direction to account for the experimental results which were obtained, while the effect on permeability would tend to be opposite to the results obtained. The stress is inversely proportional to  $1-f$ ,



while the dependence of stress on permeability is less direct. In addition, there is no direct relation between porosity and permeability (ref. 6). Further information is required on the effects of composition and density on material properties. However, char removal as a result of internal pressure appears to be consistent with the data.

High Enthalpy Tests (Condition III, Table 2).— The effects of density on effectiveness of phenolic-nylon in a high enthalpy environment is shown in figure 7. As noted previously, the effectiveness in this environment is based on the thickness of material degraded rather than on a back surface temperature rise. That is,

$$\bar{E} = \frac{\dot{q}t}{\rho l_p} \quad (5)$$

where the test duration  $t$  is specified in advance of the test. Therefore, these results are not directly comparable to those obtained at low enthalpy.

Under this test condition, the effectiveness is seen to reach the highest value at the lowest densities. Between 20 and 30 lb/ft<sup>3</sup>, the curve is relatively flat. The chars formed from low-density material in a high-enthalpy environment (Fig. 8) are much higher quality than those which were formed from the same material in a low-enthalpy environment (Fig. 3). This accounts for the high effectiveness of the low-density material.

The effect of composition on performance is shown in Figure 9. Effectiveness is relatively insensitive to nylon content. Higher Microballoon content apparently leads to slightly higher effectiveness.

#### Evaluation of Castable Material

The results presented in the preceding sections were obtained with molded phenolic-nylon. The specimens which were made from castable materials were tested under condition I (Table 2) and results are shown in Figure 10. The ablative performance of the castable material is only about one-half that of the molded material. These results indicate that further development is required if heat shields are to be cast from phenolic-nylon.

To further study the ablative performance of materials fabricated from the liquid resin system, specimens molded, rather than cast, from this resin system were tested under condition III (Table 2). These results are shown in Figure 11. The results are similar to those obtained with the powdered resin system. It appears that the liquid and powdered phenolic resin can be used interchangeably if a molding process is used.

#### Evaluation of Results

In general, it has been shown that when performance is predominantly determined by thermal and chemical phenomena, the effectiveness is relatively

insensitive to composition (over the range covered here). For test Conditions I and III, peak performance is obtained with a density of about 25 lb/ft<sup>3</sup>, but the effectiveness-vs-density curve is relatively flat in the areas of this peak.

Because of the relative insensitivity of the thermo-chemical ablative performance of the phenolic-nylon-Microballoons system to the composition and density of the material, these characteristics can be selected on some other basis. Elimination of mechanical removal of char, which occurred under test Condition II (Table 2), is an important consideration. The fact that such removal is not understood quantitatively means that extra margins of safety must be provided in designs of heat shields which may be subject to this form of char removal. From the data, it is seen that mechanical char removal increases with increasing nylon content, and decreases with increasing density.

### CONCLUSIONS

1. The thermo-chemical ablative performance of low-density phenolic-nylon is relatively insensitive to composition and density over a considerable range of these parameters. Highest performance is obtained with a density of about 25 lb/ft<sup>3</sup>, but the ablative effectiveness-vs-density curve is rather flat.

2. Low-density phenolic nylon is subject to mechanical spallation under certain conditions. The data are consistent with the hypothesis that spallation is caused by tensile failure resulting from internal pressure. The spallation increases in severity with increasing nylon content and decreasing density.

3. Further effort is required if a castable system of these resins is to be developed which has ablative characteristics similar to those of the molded material. However, fabrication difficulties may be eased somewhat by the relative insensitivity of ablative performance to composition and density.

## APPENDIX

The mechanical removal of char is examined in reference 5. In that study, equations are derived and solved numerically to demonstrate that a combination of internal pressure and thermal stress can lead to periodic char removal. In the following development, simplified equations are derived to provide an approximate analytical expression for the stress inside a charring ablator. Only internal pressure is considered here, because of the probability that thermal stresses can be relieved by plastic yielding in the reaction zone.

The ultimate tensile strength of low-density phenolic nylon is shown as a function of temperature in Figure 12. At 700° F the ultimate tensile strength is less than 50 psi, and at this temperature the decomposition reactions have hardly begun. Thus it is apparent that relatively low internal pressures could result in a mechanical failure of the char.

It is assumed that the charring ablator consists of two layers, a porous char layer and an impermeable layer of uncharred material, and that gases are generated by pyrolysis at the interface between these layers at a rate  $\dot{m}_p$ . Then from Darcy's law (ref. 6), the relation between  $\dot{m}_p$  and the pressure is

$$\dot{m}_p = \frac{k_p}{\mu} \rho_g \frac{dp}{dy} \quad (A1)$$

The ideal gas law,

$$p = \frac{\rho_g RT}{M} \quad (A2)$$

is assumed to be applicable to the gaseous pyrolysis products and it is assumed that the viscosity and average molecular weight of these gases are functions of temperature as follows:

$$\mu = \mu_o \left( \frac{T}{T_p} \right) \quad (A3a)$$

$$M = M_o \left( \frac{T_p}{T} \right) \quad (A3b)$$

It is further assumed that the temperature gradient is constant through the char layer.

$$\frac{dT}{dy} = - \frac{T_s - T_p}{\delta} \quad (A4)$$

From these equations, the pressure at the pyrolysis interface is

$$p_p = \left[ \frac{\mu_o R}{2M_o T_p^2} (T_s + T_p) (T_s^2 + T_p^2) \frac{\dot{m}_p \delta}{k_p} + p_s^2 \right]^{1/2} \quad (A5)$$

In reference 7, it is shown that the pyrolysis rate is related to the heating rate approximately as follows:

$$\dot{m}_p = \frac{Q}{\Delta h_{eff}} \frac{k_t}{\sigma_{SB} \epsilon (\delta + \beta) k_p} \frac{1}{(T_s^2 + T_p^2) (T_s + T_p)}$$

where  $Q$  is the net input at the surface, including radiative, convective, and combustive heating. The convective heating is corrected for mass injection and wall temperature, while radiative heating is corrected for surface absorptivity but not for emission from the surface. Then the pressure at the pyrolysis interface is

$$p_p = \left[ \left( \frac{\mu_o R}{2\sigma_{SB} M_o T_p^2} \right) \left( \frac{\delta}{\delta + \beta} \right) \frac{Q k_t}{\epsilon \Delta h_{eff} k_p} + p_s^2 \right]^{1/2} \quad (A6)$$

Then the stress is

$$\sigma = \frac{(f p_p - p_s)}{1 - f} \quad (A7)$$

$$\sigma = \frac{\left\{ f \left[ \frac{\mu_o R}{2\sigma_{SB} M_o T_p^2} \left( \frac{\delta}{\delta + \beta} \right) \frac{Q k_t}{\epsilon \Delta h_{eff} k_p} + p_s^2 \right]^{1/2} - p_s \right\}}{(1 - f)} \quad (A8)$$

Failure should occur when this stress reaches the ultimate tensile strength of the material.

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TABLE 1.- SUMMARY OF MATERIALS AND TEST RESULTS

Composition, percent by weight			Type of material, m.....molded c.....cast m <sub>c</sub> .....molded from castable material	Block density, $\frac{\text{lb}}{\text{ft}^3}$	E, $\frac{\text{Btu}}{\text{lb}}$  (Condition I)	$\bar{E}$ , $\frac{\text{Btu}}{\text{lb}}$  (Condition III)	$\rho_{\text{char}}^{\text{B}}$ , $\frac{\text{lb}}{\text{ft}^2\text{-sec}}$  (Condition II)
Phenolic	Nylon	Microballoons					
25 ↓	50 ↓	25 ↓	m ↓ m <sub>c</sub> m <sub>c</sub>	21 24 31 35 43 30 35	12,420 14,445 14,900 14,270 11,750 ----- -----	----- 14,050 14,450 ----- 10,450 14,300 14,420	----- 0.070 .030 .011 .011 ----- -----
15 ↓	50 ↓	35 ↓	m ↓	19 25 30 36 42	13,320 15,425 14,150 14,225 12,590	15,500 16,200 15,450 18,400* 12,750	0.126 .050 .019 .034 .016
25 ↓	40 ↓	35 ↓	m ↓ m <sub>c</sub>	18 23 30 37 43 35	13,100 13,850 13,815 13,850 11,460 -----	17,000 16,200 16,100 13,750 ----- 12,800	0.042 .024 .004 0 0 -----
35 35	30 30	35 35	m m	24 30	14,600 -----	13,100 15,200	----- -----
35	50	15	m	36	13,250	16,600*	-----
25	60	15	m	36	13,665	16,700*	-----
15	60	25	m	36	13,015	17,000*	-----
35 35	40 40	25 25	m m	37 30	12,780 -----	17,100* 14,700	----- -----
25	60	15	c	28	7,670	-----	-----
25	50	25	c	21	8,840	-----	-----
15	50	35	c	18	8,990	-----	-----
35	50	15	c	27	7,979	-----	-----
35	40	25	c	17	8,295	-----	-----
25	40	35	c	16	8,210	-----	-----

\*Indicates  $\bar{E}$  based on test time of 60 seconds.

TABLE 2.- SUMMARY OF TEST CONDITIONS

Test condition	Test parameter				Termination of tests
	$q$ , Btu ft <sup>2</sup> -sec	$h_e$ , Btu lb	$p$ , atm	Stream composition	
I	110	2,300	1.0	97 percent N <sub>2</sub> 3 percent O <sub>2</sub>	Tests stopped when back surface temperature increased 300° R
II	350	2,300	1.8	97 percent N <sub>2</sub> 3 percent O <sub>2</sub>	All tests stopped at 10 sec
III	500	12,500	1.0	Air	Tests were stopped at 30 or 60 sec

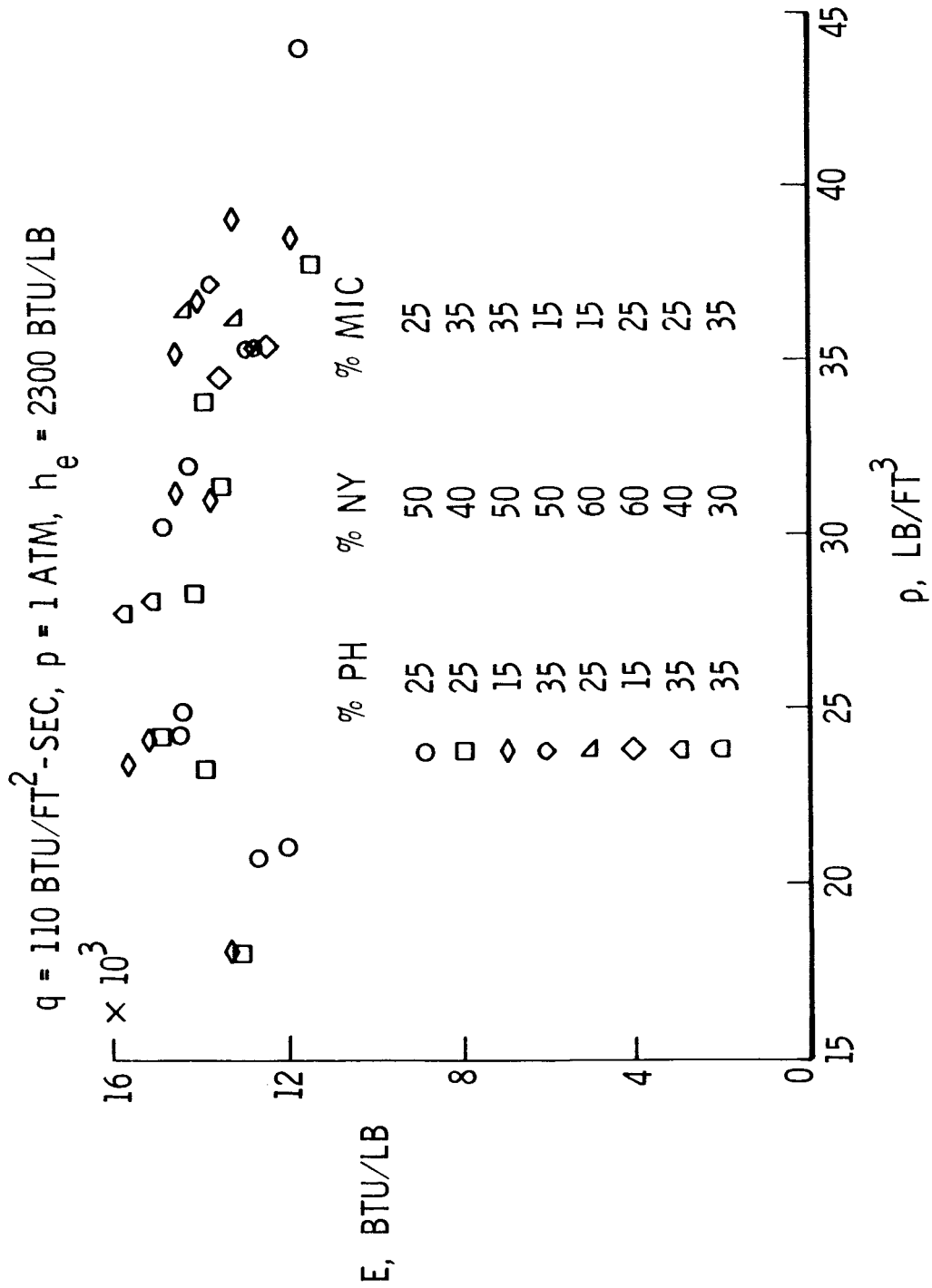


Figure 1.- Effect of density on the effectiveness of phenolic-nylon at test condition I.



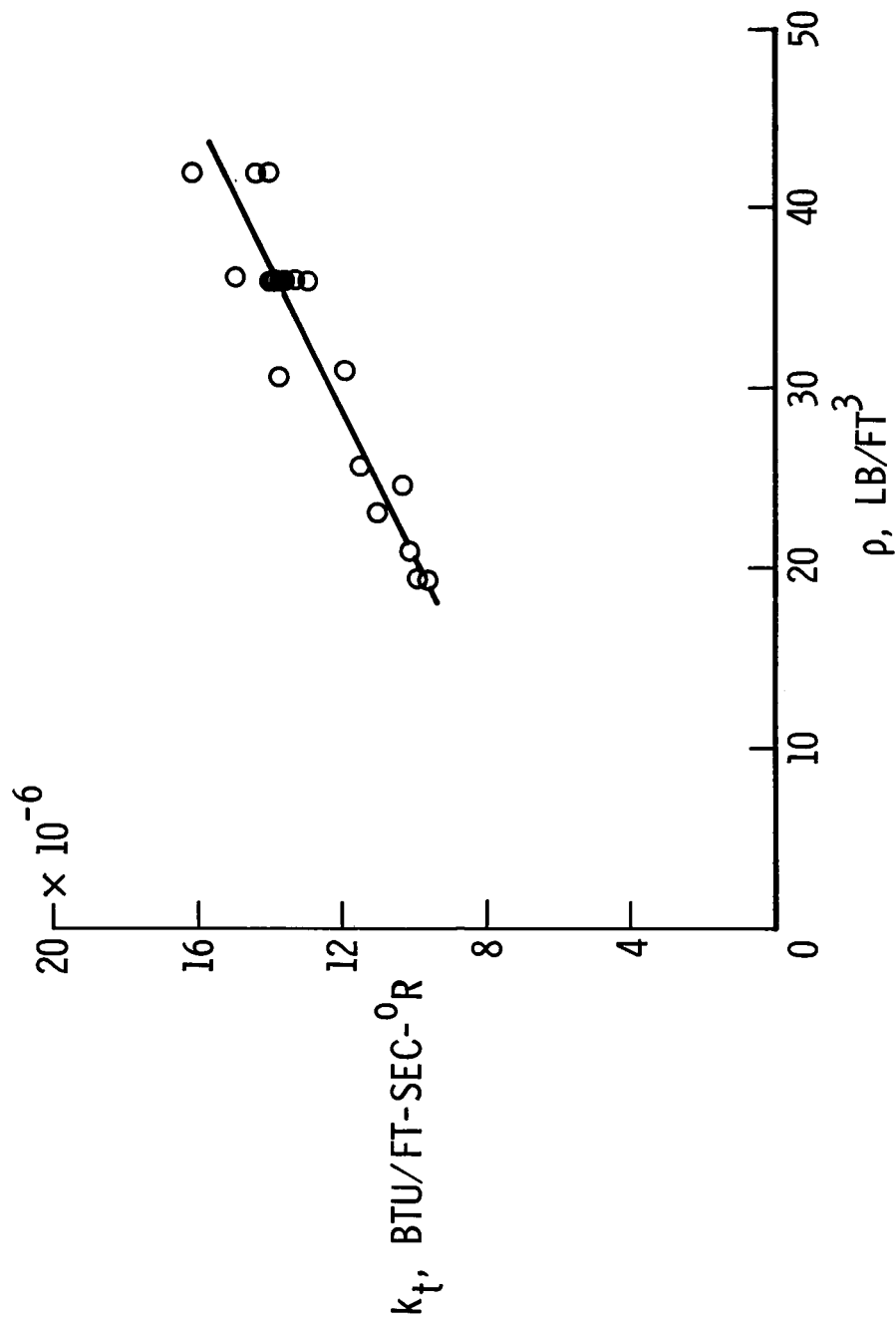
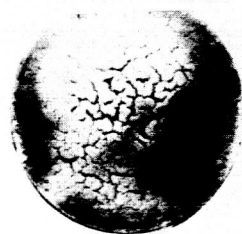
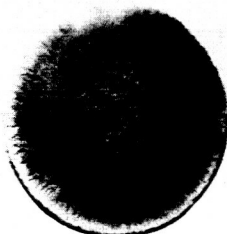


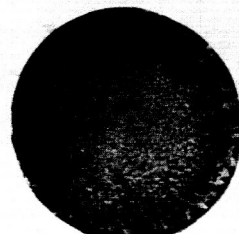
Figure 2.- Effect of density on thermal conductivity of uncharred material.



$\rho = 21 \text{ LB/FT}^3$

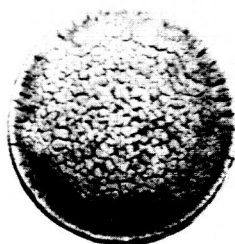


$\rho = 34 \text{ LB/FT}^3$



$\rho = 40 \text{ LB/FT}^3$

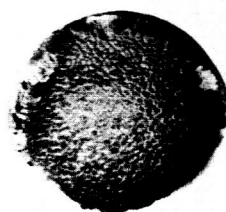
(a) 25 - 50 - 25



$\rho = 19 \text{ LB/FT}^3$

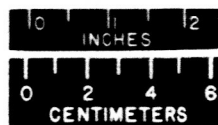


$\rho = 33 \text{ LB/FT}^3$



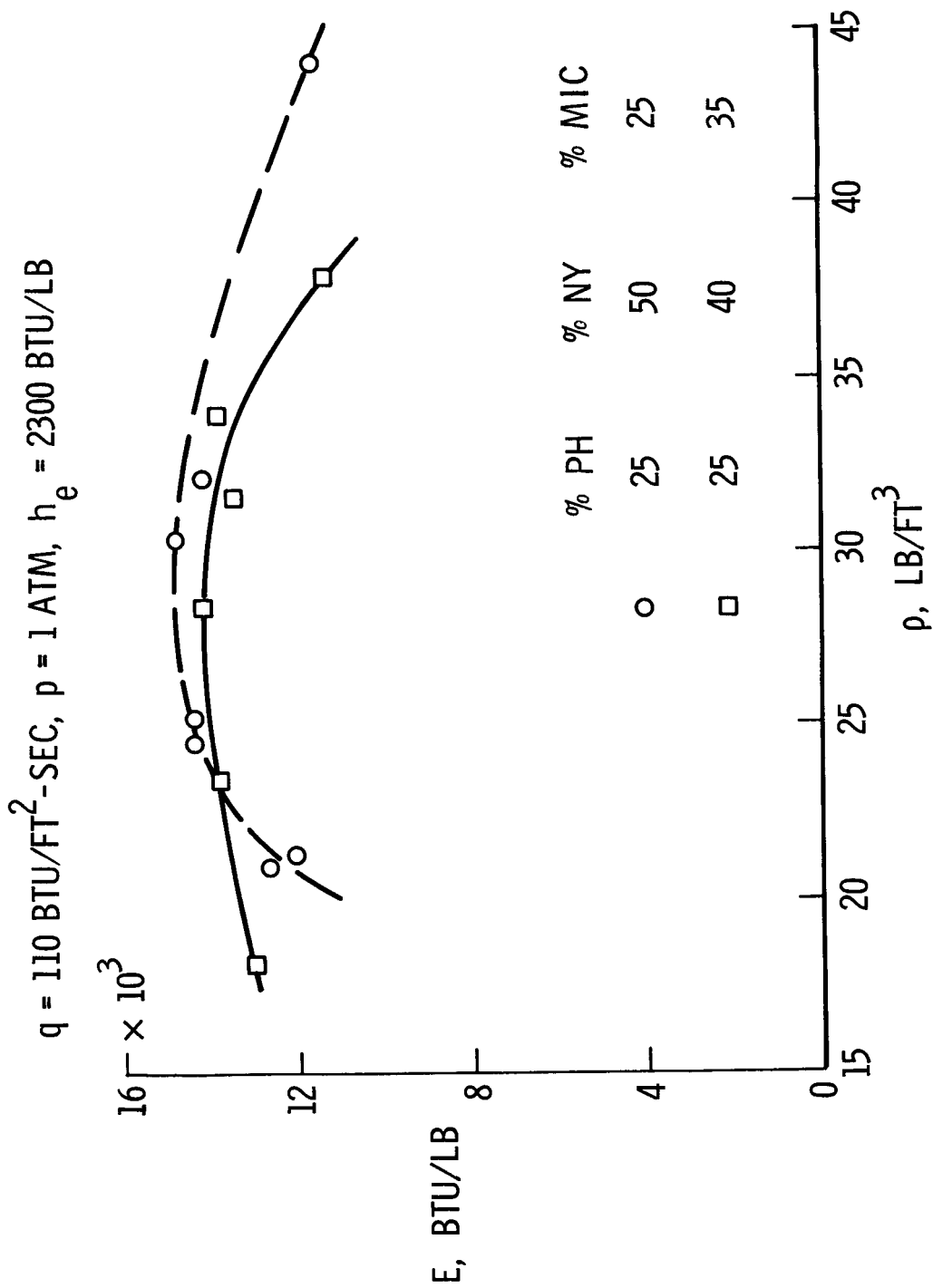
$\rho = 38 \text{ LB/FT}^3$

(b) 25 - 40 - 35



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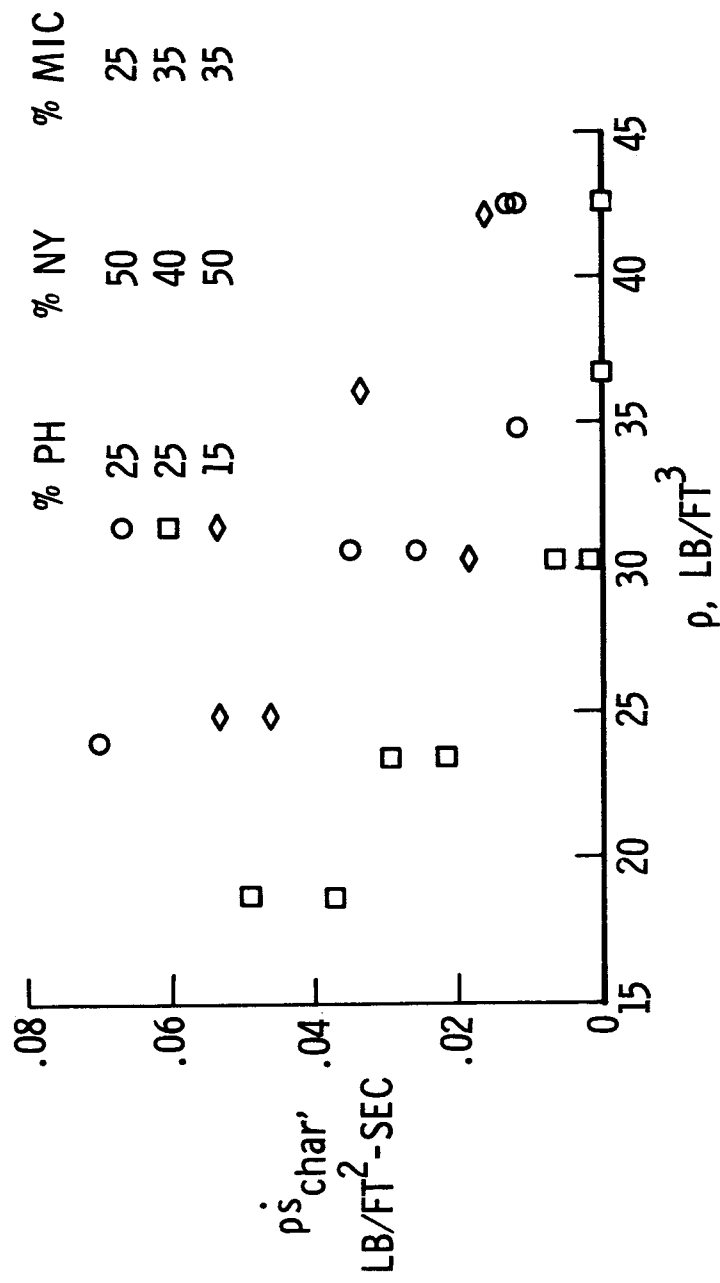
Figure 3.- Surface condition after testing in condition I.



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Figure 4.- Combined effect of density and composition on effectiveness at test condition I.

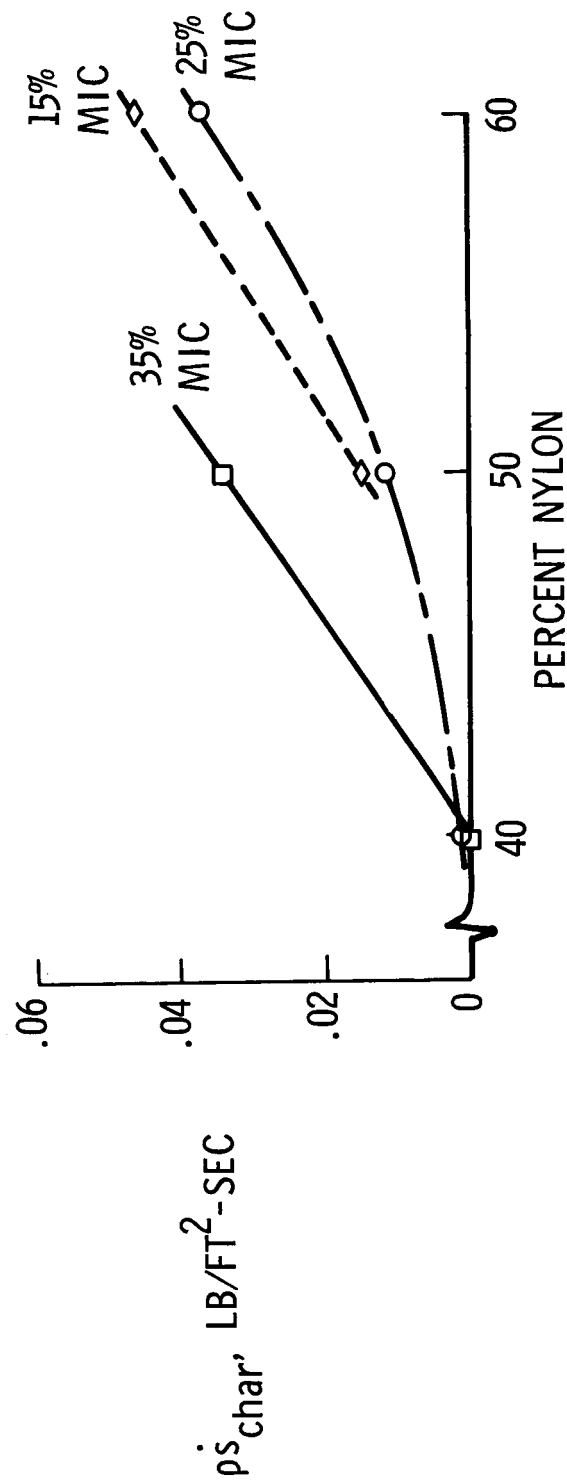
$$q = 350 \text{ BTU/FT}^2\text{-SEC}, p = 1.8 \text{ ATM}, h_e = 2300 \text{ BTU/LB}$$



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Figure 5.- Combined effect of density and composition on surface recession at test condition II.

$q = 350 \text{ BTU/LB}$ ,  $p = 1.8 \text{ ATM}$ ,  $h_e = 2300 \text{ BTU/LB}$



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Figure 6.- Effect of nylon content on surface recession at test condition II.

$q = 500 \text{ BTU/FT}^2\text{-SEC}, p = 1 \text{ ATM}, h_e = 12,500 \text{ BTU/LB}$

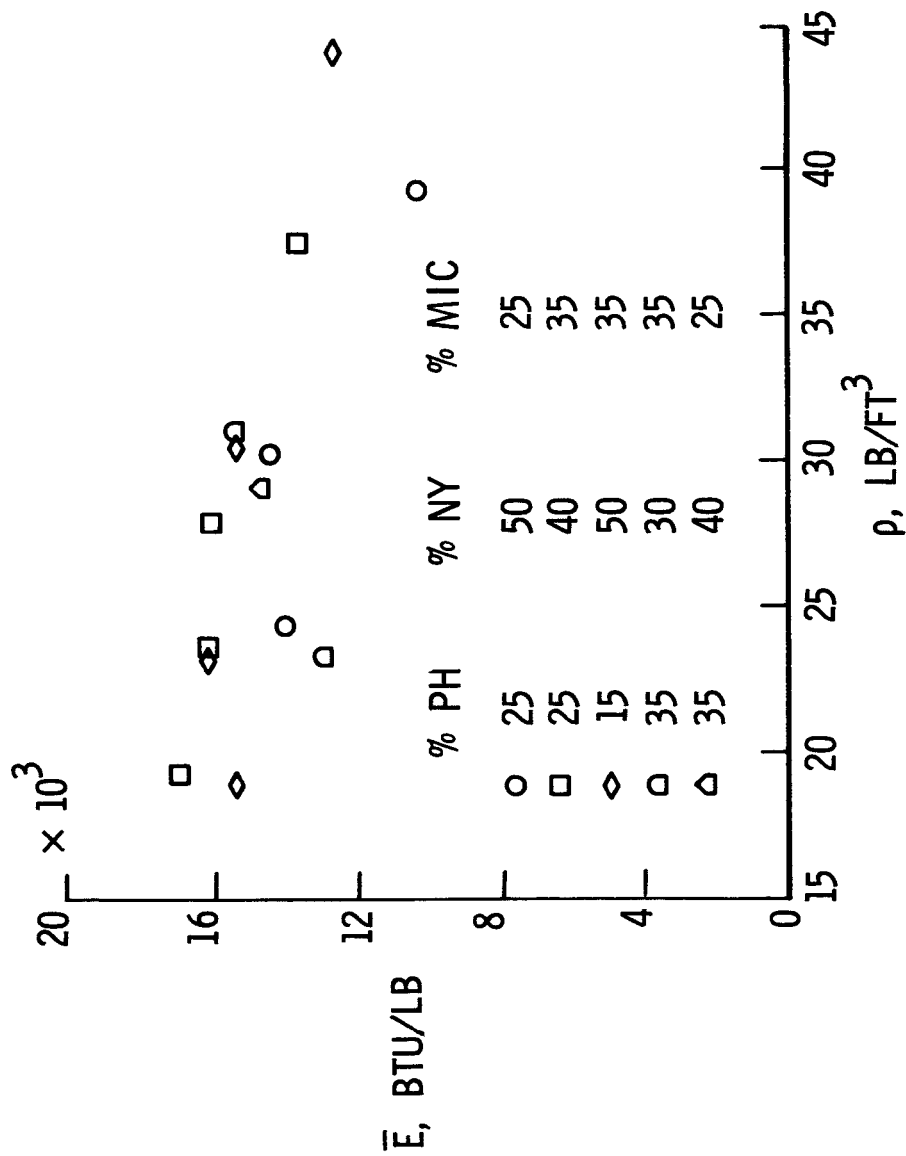
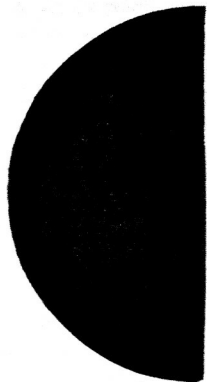


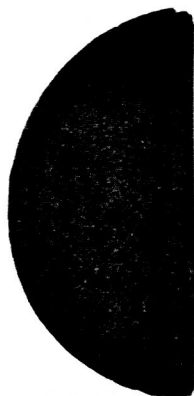
Figure 7.- Effect of density on effectiveness at test condition III.



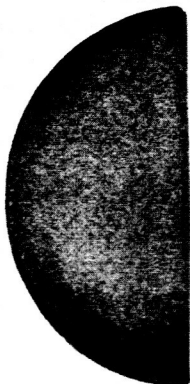
$\rho = 24 \text{ LB/FT}^3$



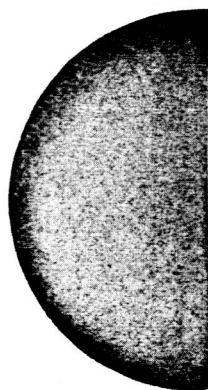
$\rho = 24 \text{ LB/FT}^3$



$\rho = 30 \text{ LB/FT}^3$

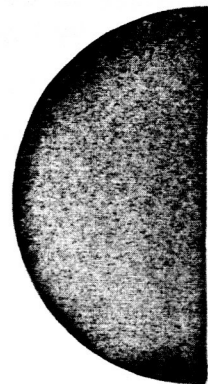


$\rho = 29 \text{ LB/FT}^3$



$\rho = 39 \text{ LB/FT}^3$

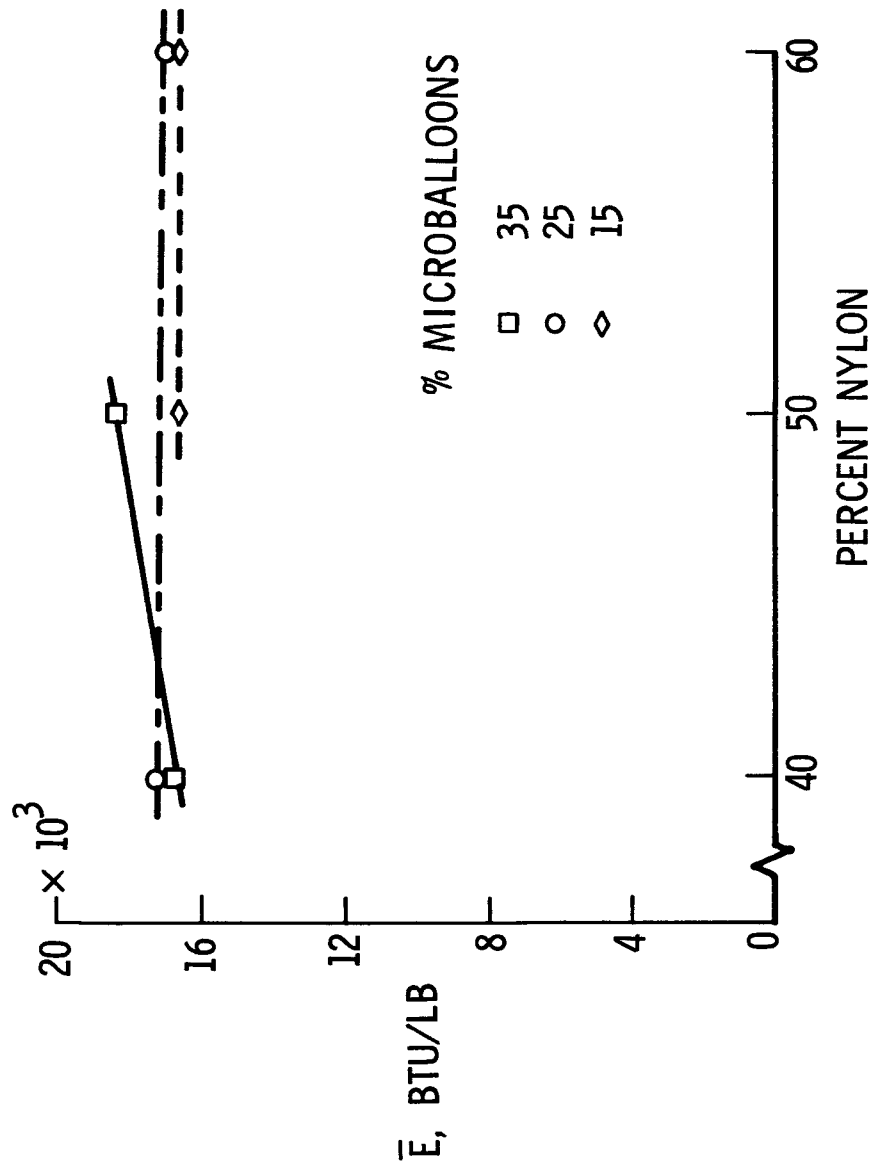
(a) 25-50-25



$\rho = 39 \text{ LB/FT}^3$

(b) 25-40-35

Figure 8.- Surface condition after testing in condition III.



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Figure 9.- Effect of nylon content on effectiveness at test condition III.



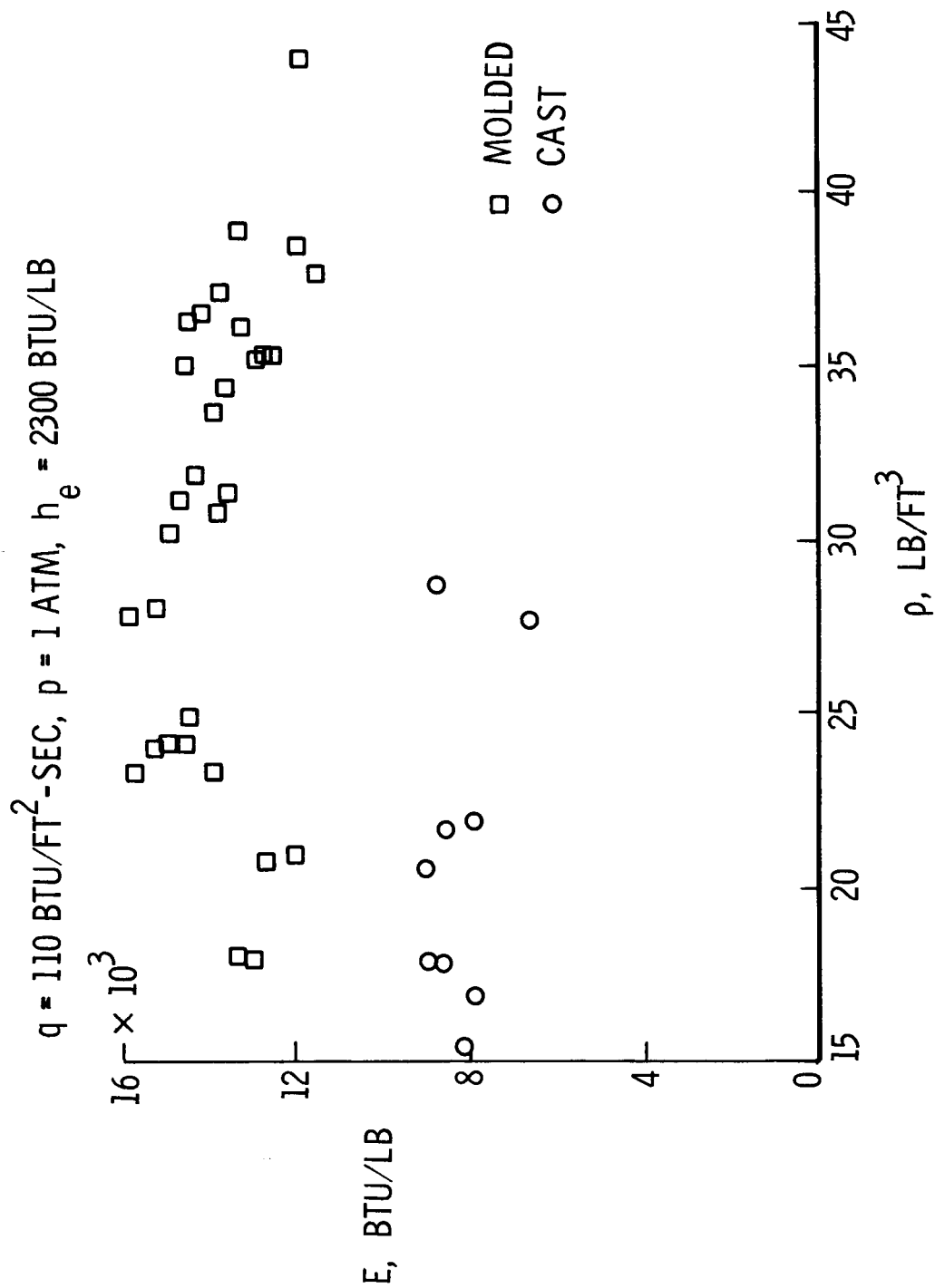
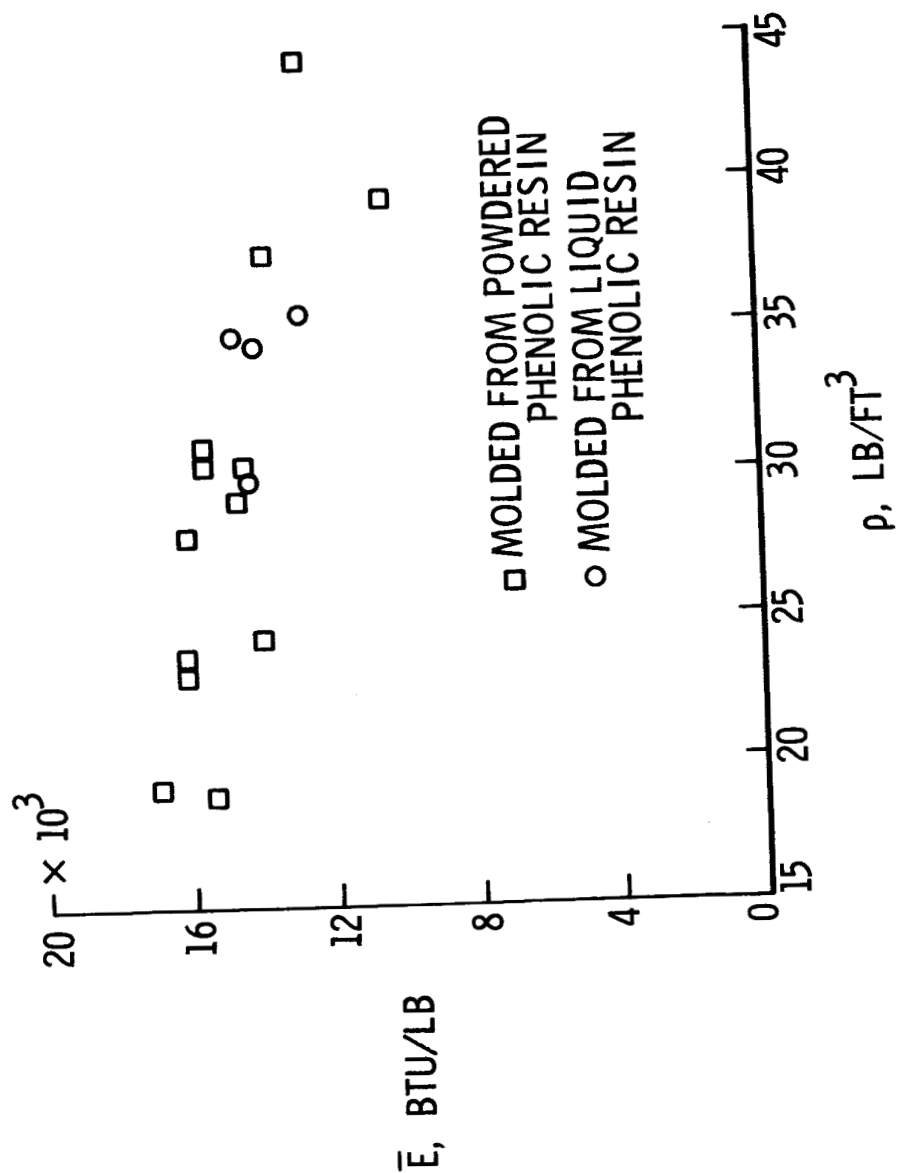


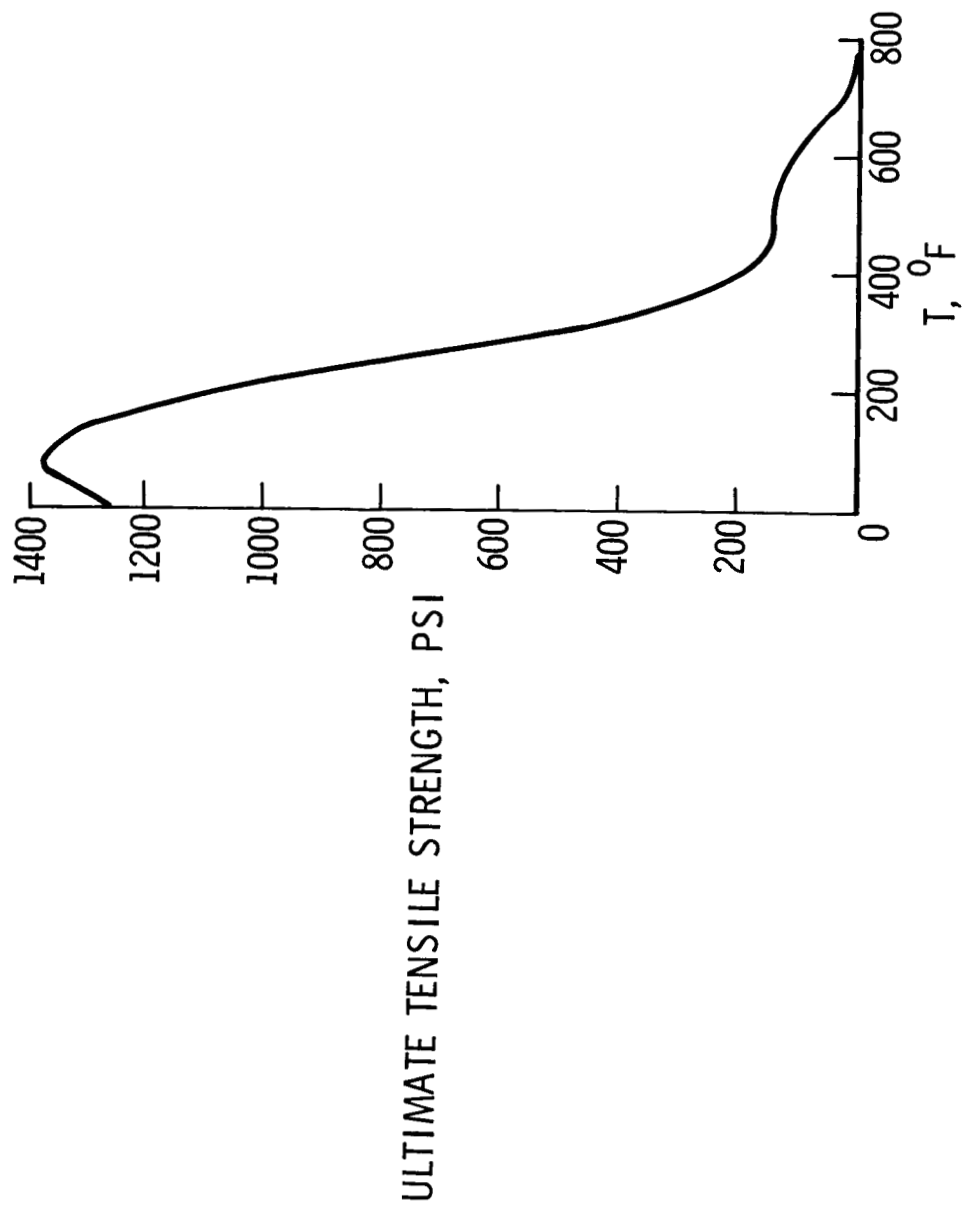
Figure 10.- Effectiveness of molded and cast phenolic nylon at test condition I.

$q = 500 \text{ BTU/FT}^2\text{-SEC}, p = 1 \text{ ATM}, h_e = 12,500 \text{ BTU/LB}$



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Figure 11.- Effect of resin on ablative performance.



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Figure 12.- Ultimate tensile strength of phenolic nylon.